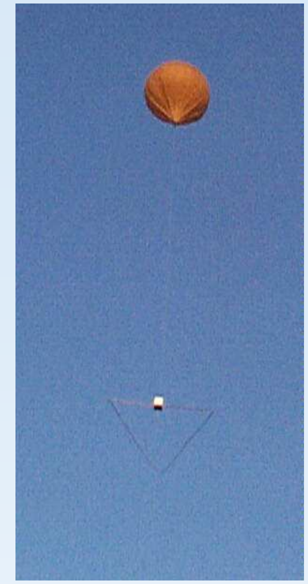
Batteries



Meaning of BATTERY

Pronunciation: 'baturee

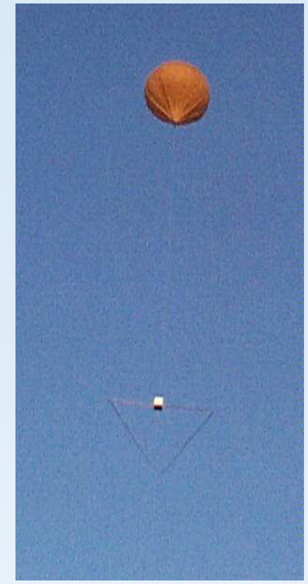
WordNet Dictionary

Definition:

1. [n] an assault in which the assailant makes physical contact
2. [n] the heavy fire of artillery to saturate an area rather than hit a specific target; "they
3. laid down a barrage in front of the advancing troops"; "the shelling went on for hours without pausing"

3. [n] a device that produces electricity; may have several primary or secondary cells arranged in parallel or series **Coined by Ben Franklin**

4. [n] a series of stamps operated in one mortar for crushing ores
5. [n] a collection of related things intended for use together; "took a battery of achievement tests"
6. [n] a unit composed of the pitcher and catcher
7. [n] group of guns or missile launchers operated together at one place

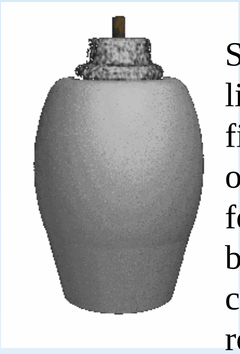


Summary

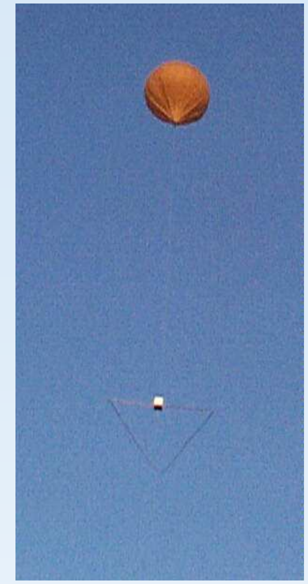
- Early History of the Battery
- Common Terms
- How a Battery Works
- Types of Batteries
- Battery Performance

Batteries

The First Battery ?

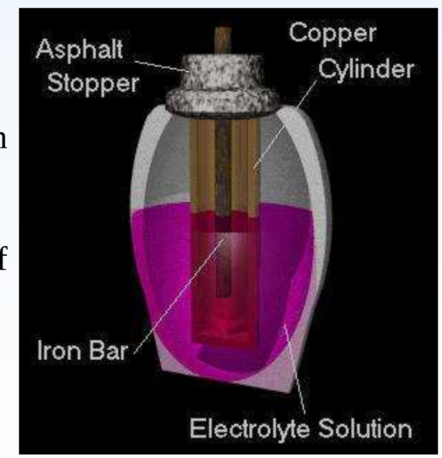


Sitting in the National Museum of Iraq is a earthenware jar about the size of a man's fist. The little jar in Baghdad suggests that Volta didn't invent the battery, but reinvented it. The jar was first described by German archaeologist **Wilhelm Konig** in 1938. It is unclear if Konig dug the object up himself or located it within the holdings of the museum, but it is known that it was found, with several others, at a place called Khujut Rabu, just outside Baghdad. The jars are believed to be about 2,000 years old and consist of an earthenware shell, with a stopper composed of asphalt. “Sticking through the top of the stopper is an iron rod. Inside the jar the rod is surrounded by a cylinder of copper.” Konig thought these things looked like electric batteries and published a paper on the subject in 1940.



World War II prevented immediate follow-up on the jars, but after hostilities ceased, an American, **Willard F. M. Gray** of the General Electric High Voltage Laboratory in Pittsfield, Massachusetts, built some reproductions. When filled with an electrolyte like grape juice, the devices produced about two volts. Not all scientists accept the "electric battery" description for the jars.

Khujut Rabu was a settlement of a people called the Parthians. While the Parthians were excellent fighters, they had not been noted for their technological achievements and some reseachers have suggested they obtained the batteries from someone else. There is nothing about the Baghdad batteries that is high-tech. All the materials used are common in origin and the manufacture was well within the ability of many of the peoples of that era. What is surprising about the jars is that somebody figured out how to put the right materials together in the right way to make a device that has a function which was not obvious. It is likely that the batteries (if that is what they are) the result of an isolated and accidental development.



What might they have been used for? German researcher **Dr. Arne Eggebrecht** used copies of the batteries to electroplate items. The electroplating process uses a small electric current to put a thin layer of one metal (such as gold) on to the surface of another (such as silver). Eggebrecht suggests that many ancient items in museums that are thought to be gold may actually be gold-plated silver.

So are these devices batteries? It certainly is a strong possibility.

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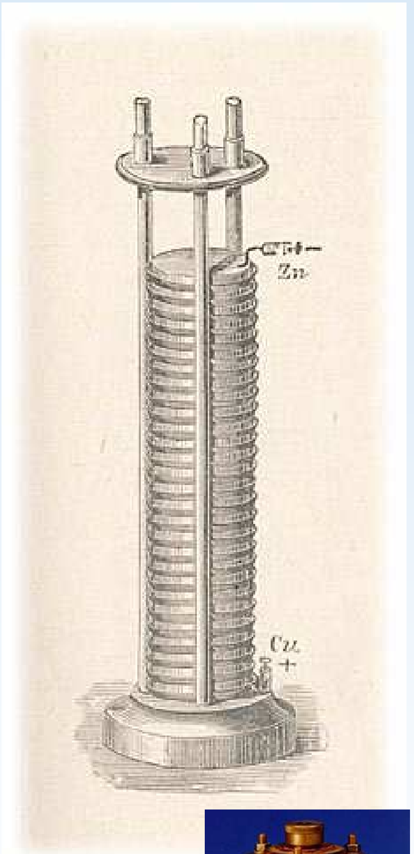
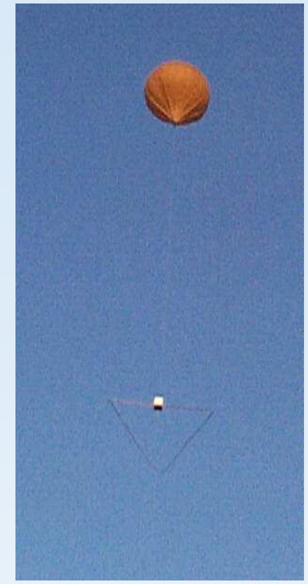
Batteries





Volta's pile - the first battery (1800) : from frogs to electricity

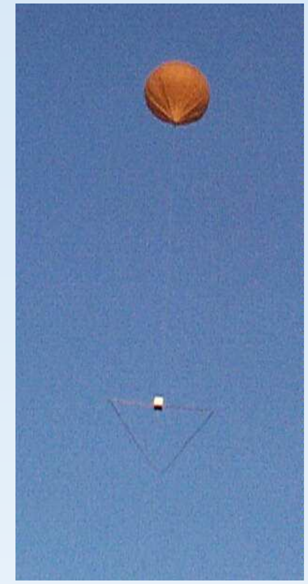
In 1780 the Italian anatomist Luigi Galvani constructed a crude electric cell with two different metals and the natural fluids from a dissected frog. Benjamin Franklin in the USA and George Adams in England were also studying the possible medical benefits of electricity around this time. But the more immediately useful result of Galvani's experiment was the electric battery.

In 1800 Alessandro Volta modified Galvani's cell by substituting other metals and replacing the frog tissue with wet pasteboard, creating a stack of several cells; the result was an electrical battery capable of holding a significant charge of several 'volts' (named after Volta).

There was great hope of using the galvanic battery in medical cures, even of bringing the dead back to life - with some bizarre experiments on the bodies of recently hanged criminals. But what it really meant was that for the first time there was a source of electric current that could be stored - and turned on and off at will.

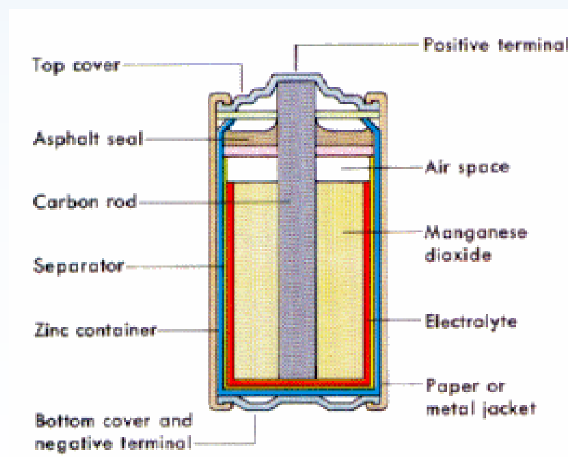
Batteries

1859 - Gaston Plante of France: lead-acid cell
still used in cars today



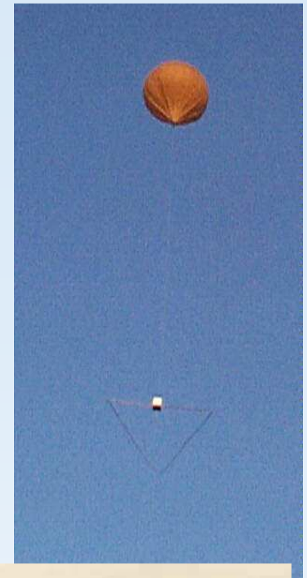
1866 - **Georges Leclanche was a French engineer who in about 1866 invented the battery that bears his name. In slightly modified form, the Leclanche battery, now called a dry cell, is produced in great quantities used in devices such as flashlights and portable radios.**

$$Zn(s) + 2\ MnO_2(s) + 2\ NH_4Cl(aq) \dashrightarrow ZnCl_2(aq) + Mn_2O_3(s) + 2\ NH_3(aq) + H_2O$$



Batteries

1896 - National Carbon Company of San Francisco first consumer battery: 6” zinc-carbon telephone



1898 - Conrad Hubert: Size-D zinc-carbon inside a paper tube with a bulb “first hand torch”

1899 - Waldmar Jungner: Ni-Cd

1947 - George Neumann perfects the Ni-Cd

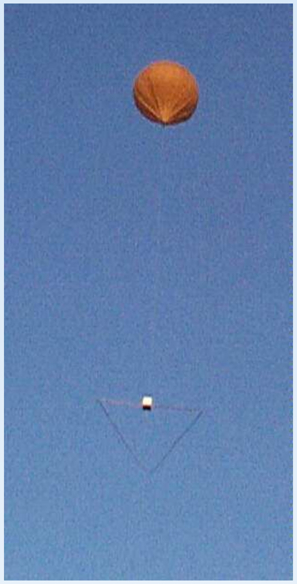
1959 - Eveready -- Lew Urry alkaline battery Parma, Ohio

Alkaline batteries last five to eight times as long as zinc-carbon cells

1967- Berkely Labs: Lithium battery

1990- NiMH 1999 - Lithium Oxide

Terms



Primary Battery- non-rechargeable battery
chemical reaction is not easily reversible

Secondary Battery - rechargeable battery
easily reversed chemical reaction

Capacity - available output of battery

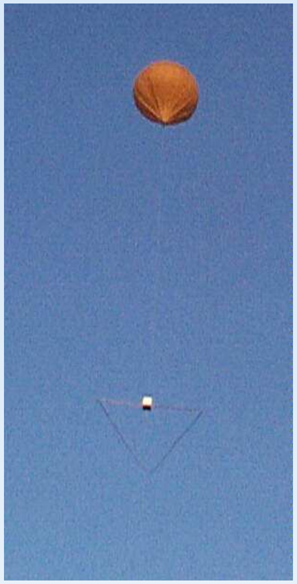
Amp-Hours or A•h - measure of battery capacity
amps are coulombs/sec = 6.25×10^{18} electrons/sec.

Voltage - Potential across battery/ energy transfer

Charge - state of battery, capacity remaining

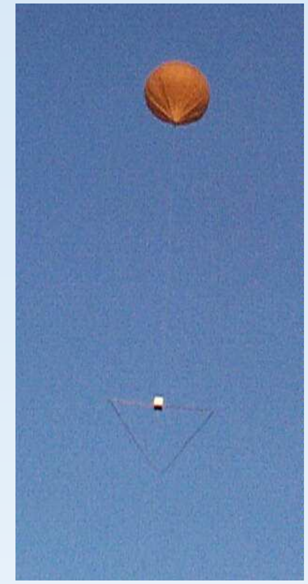
Discharge - state of battery, capacity used

Batteries



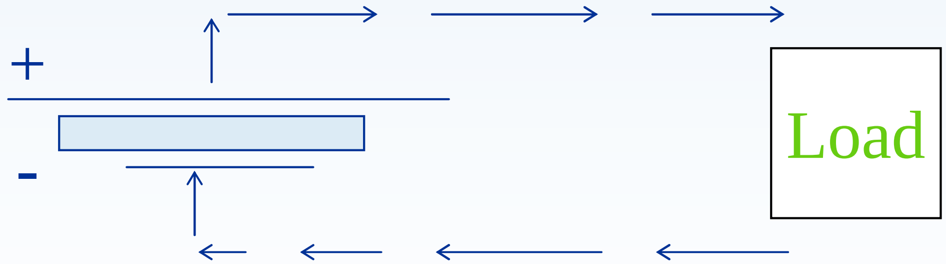
Anode - Oxidation occurs here (positive)
Cathode - Reduction occurs here (negative)
Half Cell - either reduction or oxidation part of cell
every cell/battery is made up of two half cells
Reduction - gaining electrons
Oxidation - losing electrons
Electrolyte - (salt bridge) conductive material between anode and cathode. a liquid that helps electrons move

How Does A Battery Work ?

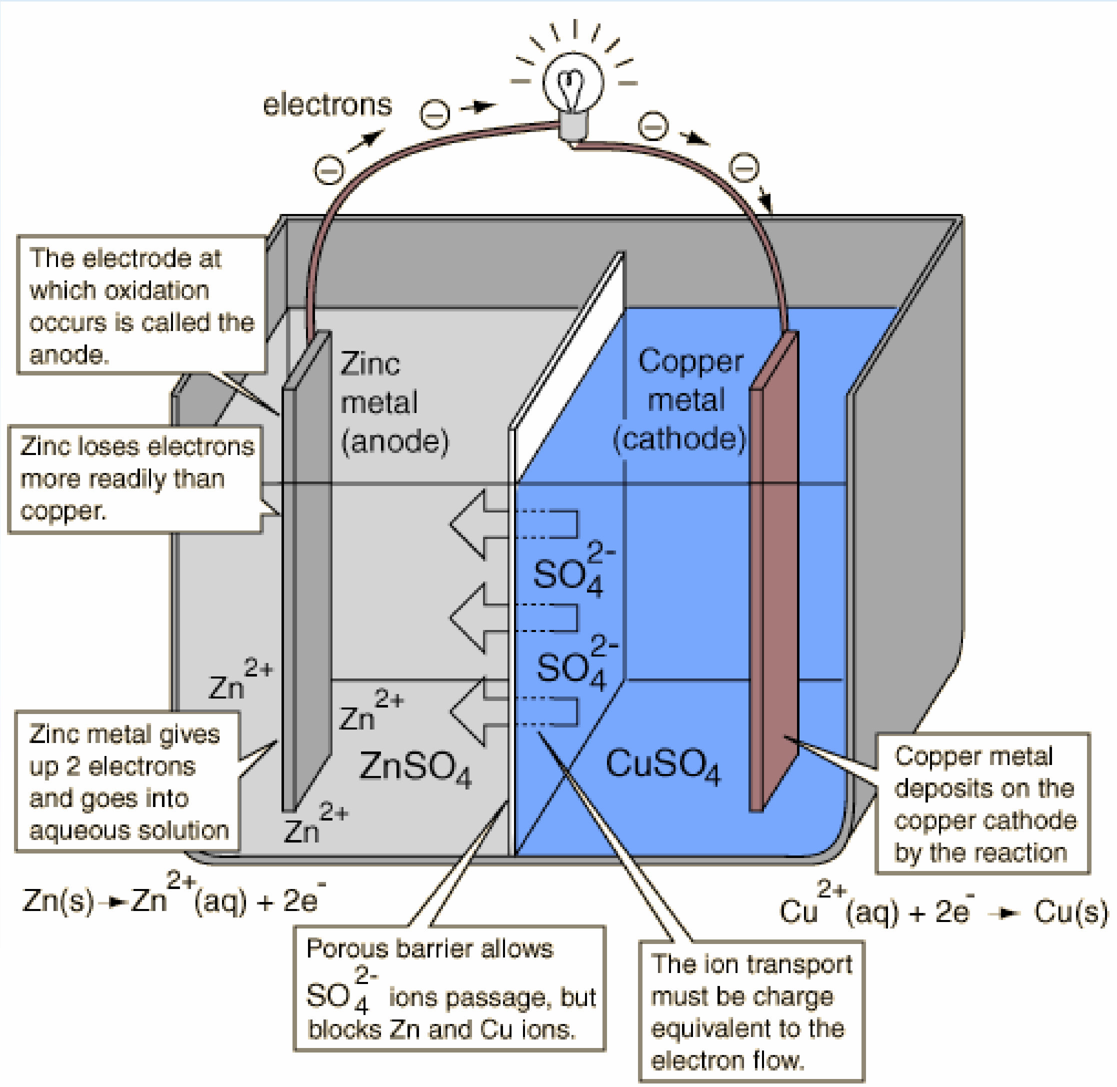


Every Battery has Three Components

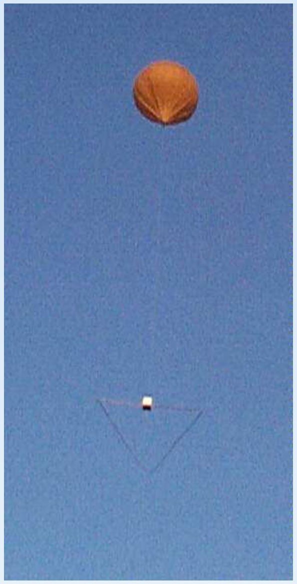
Anode - oxidation
Cathode - reduction
Electrolyte - charge carrier



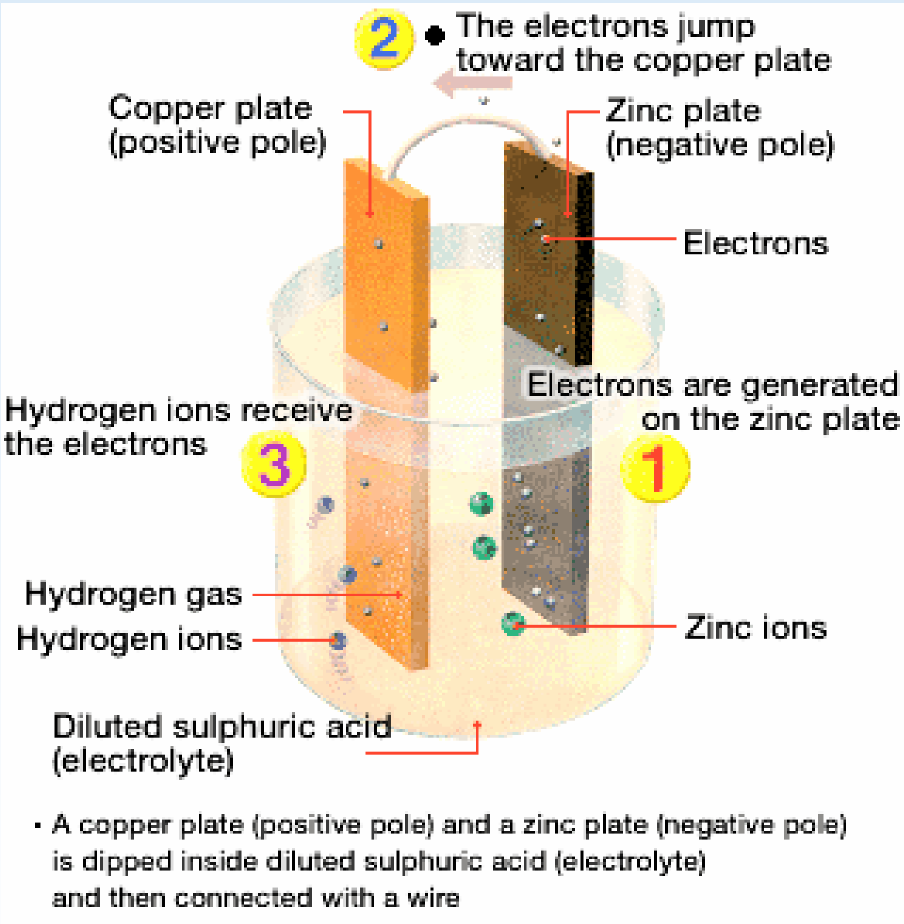
Batteries

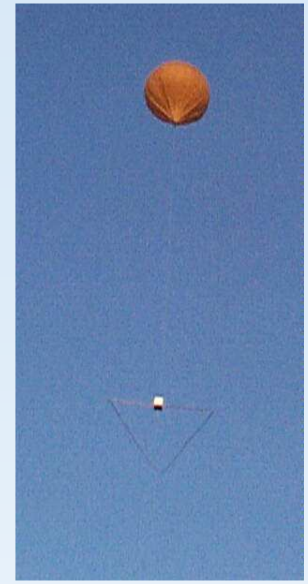


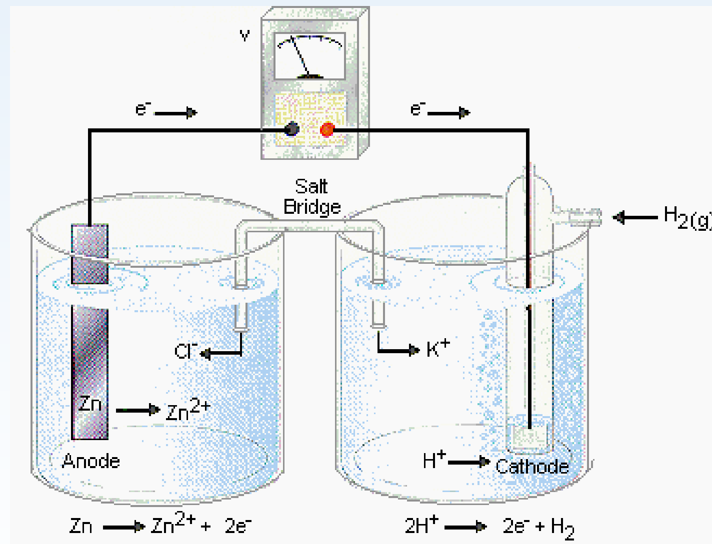
electrons
The electrode at which oxidation occurs is called the anode.
Zinc loses electrons more readily than copper.
Zinc metal (anode)
Copper metal (cathode)
SO_4^{2-}
SO_4^{2-}
Zn^{2+}
Zn^{2+}
Zn^{2+}
$ZnSO_4$
$CuSO_4$
Zinc metal gives up 2 electrons and goes into aqueous solution
$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$
Copper metal deposits on the copper cathode by the reaction
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$
Porous barrier allows SO_4^{2-} ions passage, but blocks Zn and Cu ions.
The ion transport must be charge equivalent to the electron flow.



Batteries





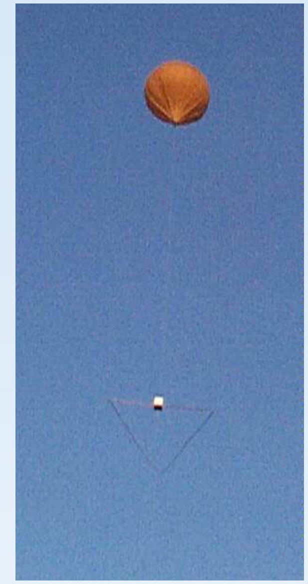


Zinc-Copper

Zinc-Hydrogen

Batteries

The Electrochemical Series



Most wants to reduce (gain electrons)

Gold
Mercury
Silver
Copper
Lead
Nickel
Cadmium

Iron
Zinc
Aluminum
Magnesium
Sodium
Potassium
Lithium

Most wants to oxidize (lose electrons)

Batteries

Reduction Potentials An be used to determine battery voltage

i.e. Cu-Zn

Cu^{+} = .52 V

Zn^{2-} = -0.76 V

.52 - -.76 =1.28 V

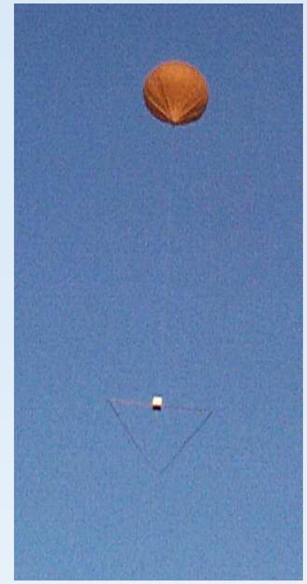
Pick and Choose

Standard Reduction Potentials at 25°C 1 M 1 atm

strong oxidizing agents ↑

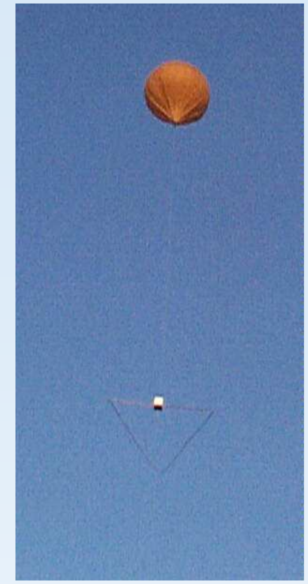
HALF-REACTION	$E°$ (V)
$F_{2(g)} + 2\,e^- \rightarrow 2\,F^-_{(aq)}$	+2.87
$O_{3(g)} + 2\,H^+_{(aq)} + 2\,e^- \rightarrow O_{2(g)} + H_2O_{(l)}$	+2.07
$Co^{3+}_{(aq)} + e^- \rightarrow Co^{2+}_{(aq)}$	+1.82
$H_2O_{2(aq)} + 2\,H^+_{(aq)} + 2\,e^- \rightarrow 2\,H_2O_{(l)}$	+1.77
$PbO_{2(s)} + 4\,H^+_{(aq)} + SO_4^{2-}{}_{(aq)} + 2\,e^- \rightarrow PbSO_{4(s)} + 2\,H_2O_{(l)}$	+1.70
$Ce^{4+}_{(aq)} + e^- \rightarrow Ce^{3+}_{(aq)}$	+1.61
$MnO_4^-{}_{(aq)} + 8\,H^+_{(aq)} + 5\,e^- \rightarrow Mn^{2+}_{(aq)} + 4\,H_2O_{(l)}$	+1.51
$Au^{3+}_{(aq)} + 3\,e^- \rightarrow Au_{(s)}$	+1.50
$Cl_{2(g)} + 2\,e^- \rightarrow 2\,Cl^-_{(aq)}$	+1.36
$Cr_2O_7^{2-}{}_{(aq)} + 14\,H^+_{(aq)} + 6\,e^- \rightarrow 2\,Cr^{3+}_{(aq)} + 7\,H_2O_{(l)}$	+1.33
$MnO_{2(s)} + 4\,H^+_{(aq)} + 2\,e^- \rightarrow Mn^{2+}_{(aq)} + 2\,H_2O_{(l)}$	+1.23
$\boxed{O_{2(g)} + 4\,H^+_{(aq)} + 4\,e^- \rightarrow 2\,H_2O_{(l)}}$	+1.23
$Br_{2(l)} + 2\,e^- \rightarrow 2\,Br^-_{(aq)}$	+1.07
$NO_3^-{}_{(aq)} + 4\,H^+_{(aq)} + 3\,e^- \rightarrow NO_{(g)} + 2\,H_2O_{(l)}$	+0.96
$2\,Hg^{2+}_{(aq)} + 2\,e^- \rightarrow Hg_2^{2+}{}_{(aq)}$	+0.92
$Hg_2^{2+} + 2\,e^- \rightarrow 2\,Hg_{(l)}$	+0.85
$Ag^+_{(aq)} + e^- \rightarrow Ag_{(s)}$	+0.80
$Fe^{3+}_{(aq)} + e^- \rightarrow Fe^{2+}_{(aq)}$	+0.77
$O_{2(g)} + 2\,H^+_{(aq)}\ 2\,e^- \rightarrow H_2O_{2(aq)}$	+0.68
$MnO_4^-{}_{(aq)} + 2\,H_2O_{(l)} + 3\,e^- \rightarrow MnO_{2(s)} + 4\,OH^-_{(aq)}$	+0.59
$I_{2(s)} + 2\,e^- \rightarrow 2\,I^-_{(aq)}$	+0.53
$O_{2(g)} + 2\,H_2O + 4\,e^- \rightarrow 4\,OH^-_{(aq)}$	+0.40
$Cu^{2+}_{(aq)} + 2\,e^- \rightarrow Cu_{(s)}$	+0.34
$AgCl_{(s)} + e^- \rightarrow Ag_{(s)} + Cl^-_{(aq)}$	+0.22
$SO_4^{2-}{}_{(aq)} + 4\,H^+_{(aq)} + 2\,e^- \rightarrow SO_{2(g)} + 2\,H_2O_{(l)}$	+0.20
$Cu^{2+}_{(aq)} + e^- \rightarrow Cu^+_{(aq)}$	+0.15
$Sn^{4+}_{(aq)} + 2\,e^- \rightarrow Sn^{2+}_{(aq)}$	+0.13
$2\,H^+_{(aq)} + 2\,e^- \rightarrow H_{2(g)}$	0.00
$Pb^{2+}_{(aq)} + 2\,e^- \rightarrow Pb_{(s)}$	-0.13
$Sn^{2+}_{(aq)} + 2\,e^- \rightarrow Sn_{(s)}$	-0.14
$Ni^{2+}_{(aq)} + 2\,e^- \rightarrow Ni_{(s)}$	-0.25
$Co^{2+}_{(aq)} + 2\,e^- \rightarrow Co_{(s)}$	-0.28
$PbSO_{4(s)} + 2\,e^- \rightarrow Pb_{(s)} + SO_4^{2-}{}_{(aq)}$	-0.31
$Cd^{2+}_{(aq)} + 2\,e^- \rightarrow Cd_{(s)}$	-0.40
$Fe^{2+}_{(aq)} + 2\,e^- \rightarrow Fe_{(s)}$	-0.44
$Cr^{3+}_{(aq)} + 3\,e^- \rightarrow Cr_{(s)}$	-0.74
$Zn^{2+}_{(aq)} + 2\,e^- \rightarrow Zn_{(s)}$	-0.76
$\boxed{2\,H_2O_{(l)} + 2\,e^- \rightarrow H_{2(g)} + 2\,OH^-_{(aq)}}$	-0.83
$Mn^{2+}_{(aq)} + 2\,e^- \rightarrow Mn_{(s)}$	-1.18
$Al^{3+}_{(aq)} + 3\,e^- \rightarrow Al_{(s)}$	-1.66
$Be^{2+}_{(aq)} + 2\,e^- \rightarrow Be_{(s)}$	-1.85
$Mg^{2+}_{(aq)} + 2\,e^- \rightarrow Mg_{(s)}$	-2.37
$Na^+_{(aq)} + e^- \rightarrow Na_{(s)}$	-2.71
$Ca^{2+}_{(aq)} + 2\,e^- \rightarrow Ca_{(s)}$	-2.87
$Sr^{2+}_{(aq)} + 2\,e^- \rightarrow Sr_{(s)}$	-2.89
$Ba^{2+}_{(aq)} + 2\,e^- \rightarrow Ba_{(s)}$	-2.90
$K^+_{(aq)} + e^- \rightarrow K_{(s)}$	-2.93
$Li^+_{(aq)} + e^- \rightarrow Li_{(s)}$	-3.05

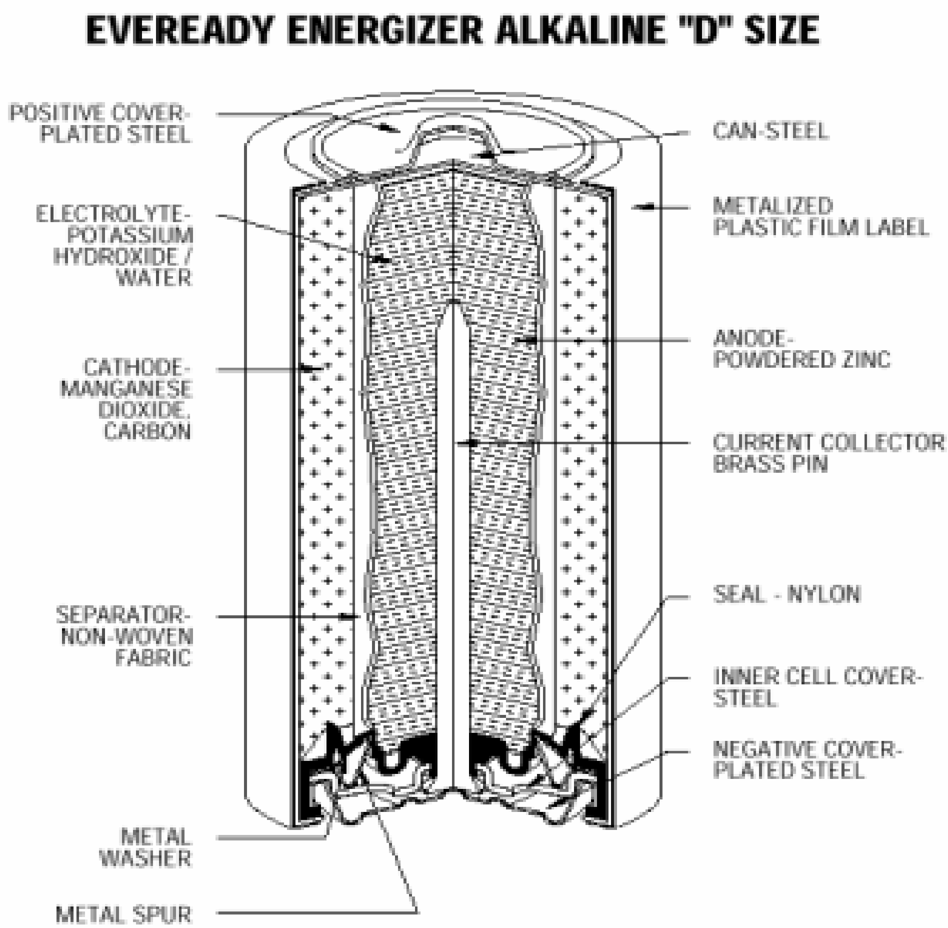
strong reducing agents ↓



Batteries

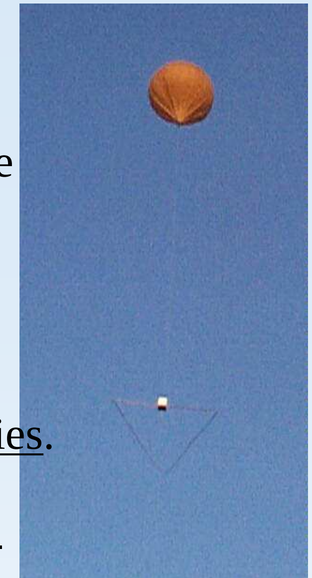
Commercial Battery





Batteries

Available Battery Types



.1 Acid vs. Alkaline

Batteries are often classified by the type of electrolyte used in their construction. There are three common classifications; acid, mildly acid, and alkaline.

Acid-based batteries often use sulphuric acid as the major component of the electrolyte. Automobile batteries are acid-based. The electrolyte used in mildly acidic batteries is far less corrosive than typical acid-based batteries and usually includes a variety of salts that produce the desired acidity level. Inexpensive household batteries are mildly acidic batteries.

Alkaline batteries typically use sodium hydroxide or potassium hydroxide as the main component of the electrolyte. Alkaline batteries are often used in applications where long-lasting, high-energy output is needed, such as cellular phones, portable CD players and radios, pagers, and flash cameras.

.2 Wet vs. Dry

"Wet" cells refer to galvanic cells where the electrolyte is liquid in form and is allowed to flow freely within the cell casing. Wet batteries are often sensitive to the orientation of the battery. For example, if a wet cell is oriented such that a gas pocket accumulates around one of the electrodes, the cell will not produce current. Most automobile batteries are wet cells.

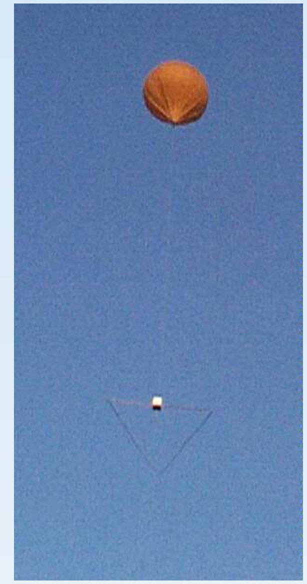
"Dry" cells are cells that use a solid or powdery electrolyte. These kind of electrolytes use the ambient moisture in the air to complete the chemical process. Cells with liquid electrolyte can be classified as "dry" if the electrolyte is immobilized by some mechanism, such as by gelling it or by holding it in place with an absorbent substance such as paper.

In common usage, "dry cell" batteries will usually refer to zinc-carbon cells (Sec. 2.3.1) or zinc-alkaline-manganese-dioxide cells (Sec. 2.3.2), where the electrolyte is often gelled or held in placed by absorbent paper.

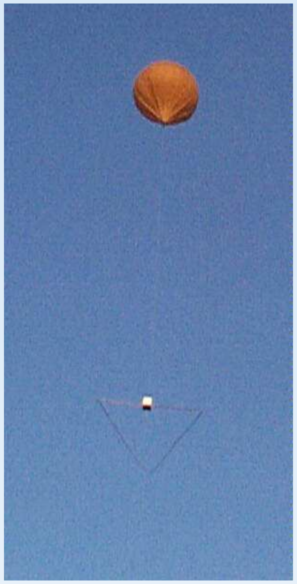
Batteries

Spirit and Opportunity are the first NASA spacecraft to carry the new batteries, which weigh about 16 pounds (7.15 kilograms) a piece

Battery: 2 per rover
Rechargeable
Lithium Ion Technology
-20° C to + 40°C



Batteries



Battery

During the times when there is either too little or no sunlight for the solar array, Sojourner can use batteries to power the Rover hardware. Battery power is used cautiously since the batteries store only a limited amount of energy and once depleted, cannot be recharged. Although they are primarily used for nighttime experiments and early morning operations on Mars, the batteries also provide power for periodic Rover communications ("health checks") during the seven month cruise from Earth.

The three batteries are normally out of sight inside the Rover's gold-colored electronics box mounted under the solar panel. Each battery looks something like a black flashlight tube (without end caps) and each tube has three D-size cells inside it. The tubes are strapped together around the Rover's suspension axle which runs through the middle of the electronics box.

Should either the batteries or the solar array fail, the Rover can complete its primary mission using the other power source.

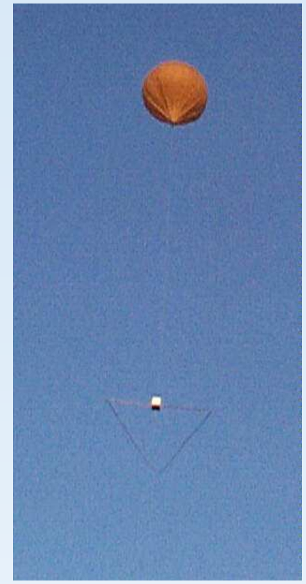
Battery Cells

Chemistry	Lithium-Thionyl Chloride (Li-SOCl2)
Size	D-Size (3 per string)
Weight	118 grams
Capacity	+25C 12 amp-hrs -20C 8 amp-hrs

The power generated by the solar array and batteries is conditioned and distributed using a complex arrangement of Power Electronics. The electronics are fully integrated with the navigation and computer electronics to save money, space, and mass, while providing more than ten different voltages to the various Rover hardware. Most of the power electronic components used are commercially available.

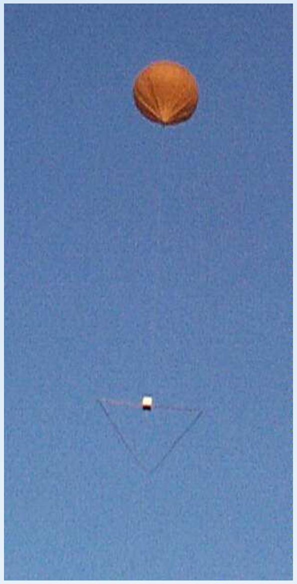
Batteries

Cell type **Nominal voltage**
Operating range (°C)
Mean Energy densities (Wh kg^{-1})
Discharge curve



Cell type	Nominal voltage	Operating range (°C)	Mean Energy densities (Wh kg^{-1})	Discharge curve
PRIMARY				
Carbon/zinc	1.5	-7 to 55	66	slope
Alkaline manganese	1.5	-30 to 65	83	plateau/slope
Mercury/zinc	1.35	-20 to 55	110	plateau
Silver/zinc	1.5	0 to 55	118	plateau
Lithiumthionylchloride	3.6	-55 to 70	420	plateau
Lithium CFX*	3.2	-40 to 85	400	plateau
SECONDARY				
Nickel-cadmium	1.2	-20 to 45	60	slope
Ni-Cd sintered	1.2	-30 to 50	40	slope
Dryfit lead-acid	2.1	-40 to 50	32	plateau>slope
MULTIPLE CELL**				
Alkaline manganese layer (6 cells)	9	-30 to 50	80	slope
Ni-Cd sintered (7 cells)	8.4	-30 to 50	40	slope

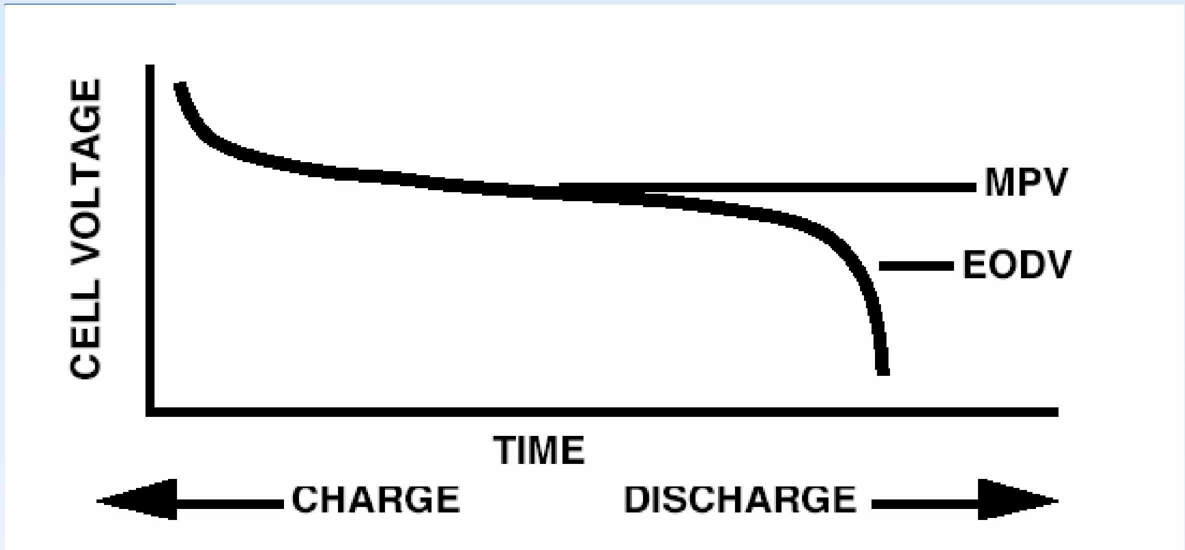
Battery Performance

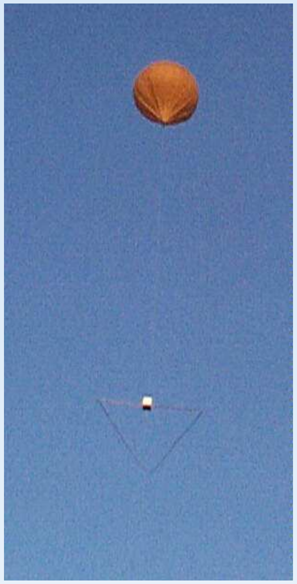


- Charge/Discharge Curves
- Power Density / Physical Capacity W/kg
- Power Density / Current Capacity - Surge
- Shelf-Life or Self Discharge
- Environmental (Temperature/Humidity)

MUST Consider Application !

Batteries





The Charge/Discharge Curve

The measured terminal voltage of any battery will vary as it is charged and discharged

The *MPV (mid-point voltage) is the nominal voltage* of the cell during charge or discharge. The maximum and minimum voltage excursion from the nominal value is an important design consideration: a "flatter" discharge curve means less voltage variation that the design must tolerate.

When peak charged, the actual cell voltage will be higher than the MPV. When nearing the *EODV (end of discharge voltage)* point, the cell voltage will be less than the MPV. The EODV is sometimes referred to as the *EOL* (end of life) voltage by manufacturers.

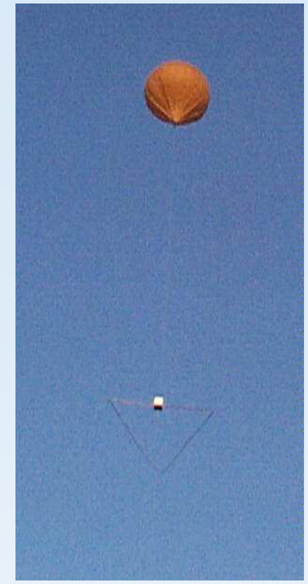
Batteries

Nickel Metal Hydride (NiMH)

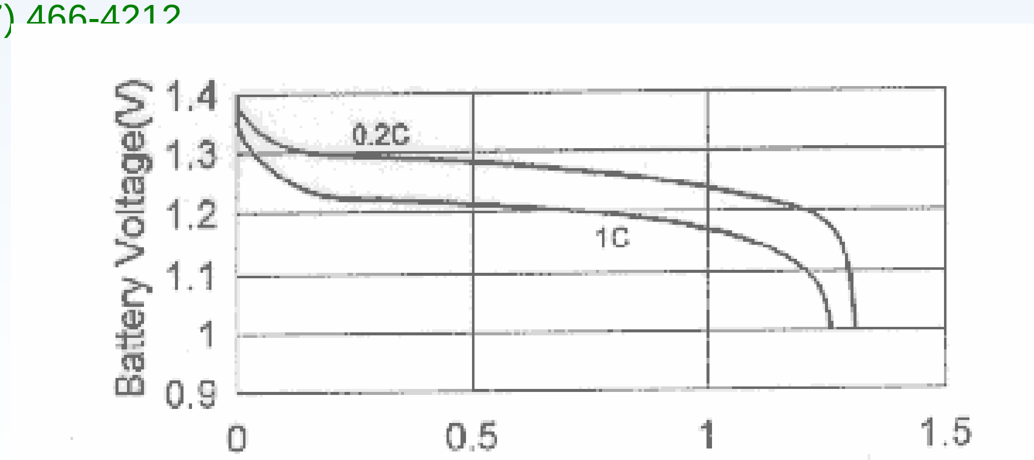
NiMH Battery Discharge Curve

This chart indicates the discharge curve of Maha NiMH battery in various discharge rates. The discharge is measured in the unit of "C", or capacity. 1.0C means 1.0 x capacity of battery (i.e. If the battery is 1,200mAh, then the discharge rate is 1,200mA or 1.2A), and 0.2C means 0.2 x capacity of battery.

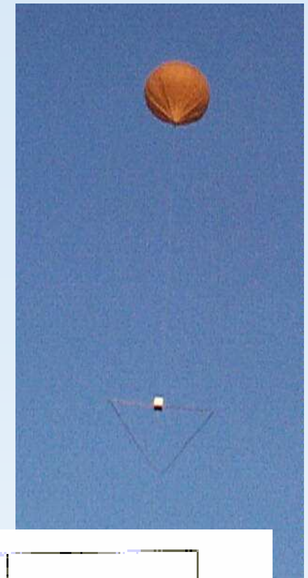
As you can see, Maha NiMH battery remains at a high voltage even near the end of the cycle. Maha NiMH battery will hold full voltage (1.2v/cell) up to 80-90% of usage (varies on discharge rate).



Thomas Distributing, 128 East Wood St., Paris, IL 61944
Phone : (217) 466-4210 Fax : (217) 466-4212

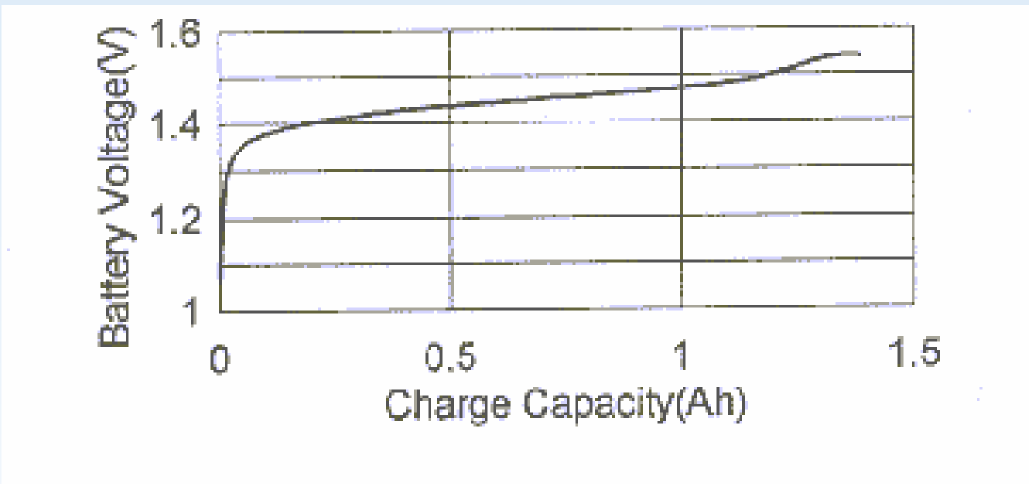


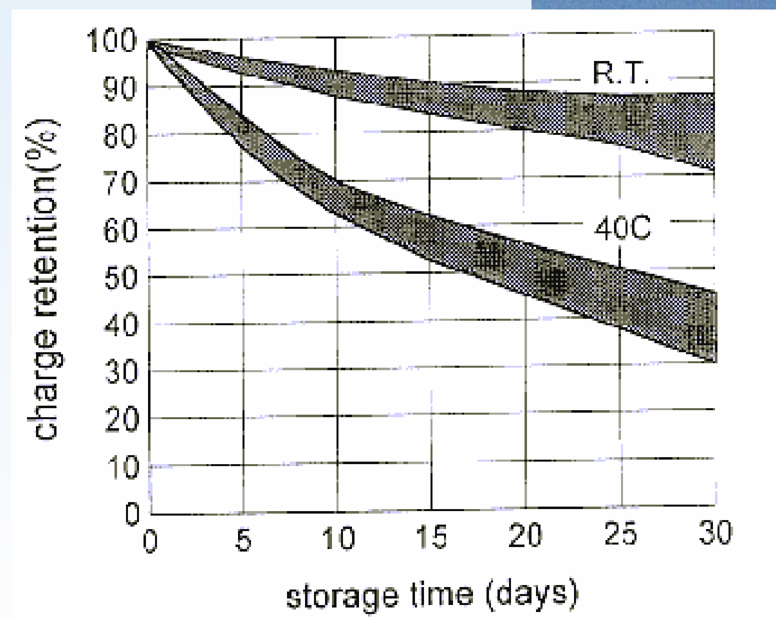
Batteries



NiMH Battery Charge Curve

This chart indicates the charge curve of general Maha batteries.





NiMH Battery Retention Curve

This chart indicates the retention curve, or the ability the battery can hold a charge. As different temperature, the battery has a different retention capability. For Maha battery, you can leave it on the shelf for a period of time without loosing all charged capacity.

Batteries

Lead Acid

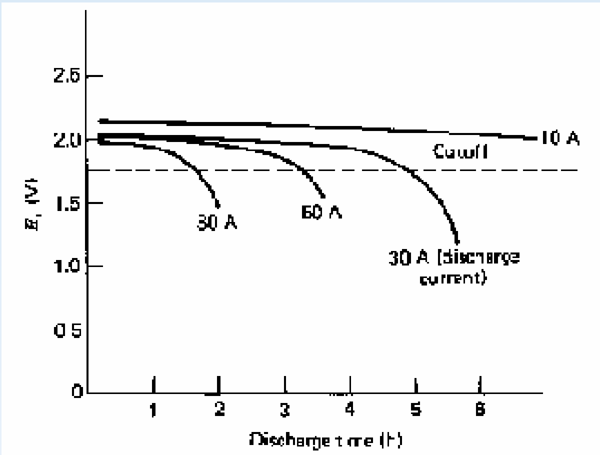
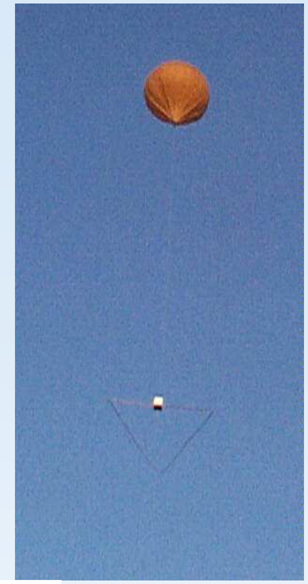
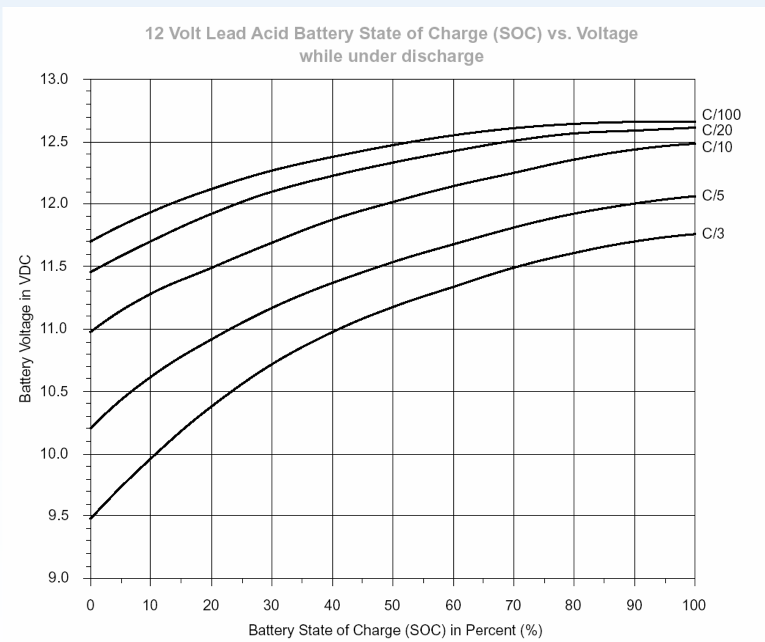
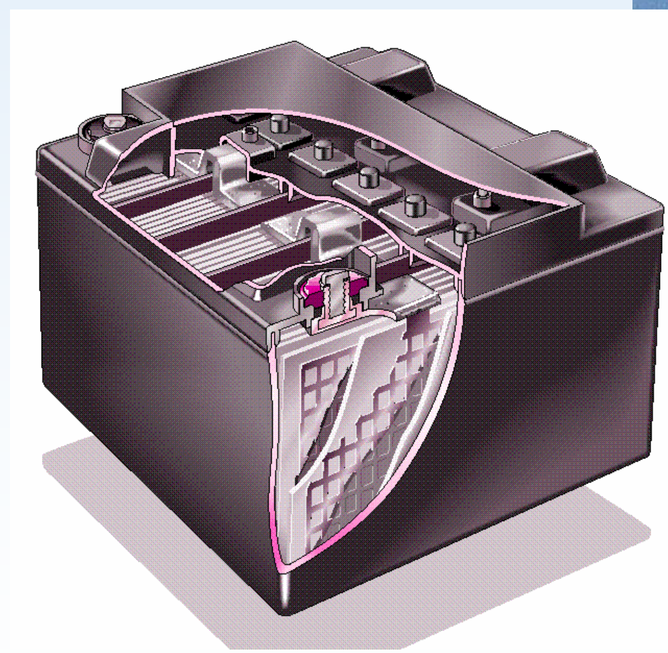
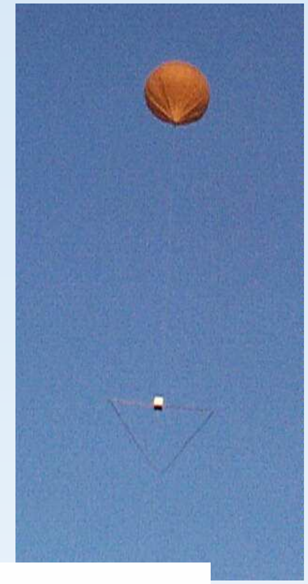


Figure 3.2. Constant current discharge tests.



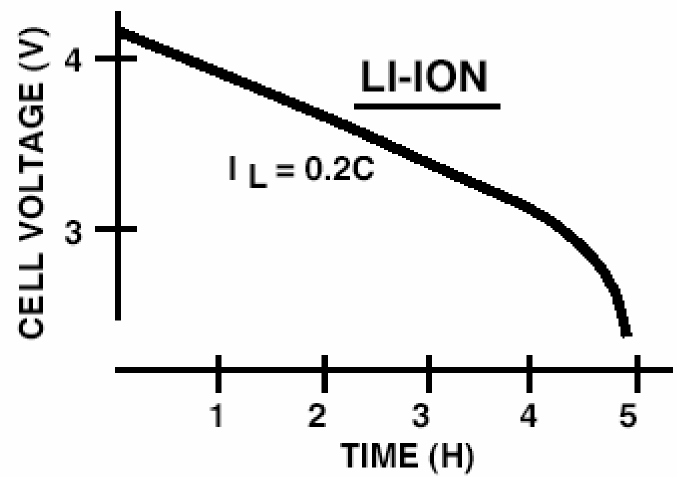


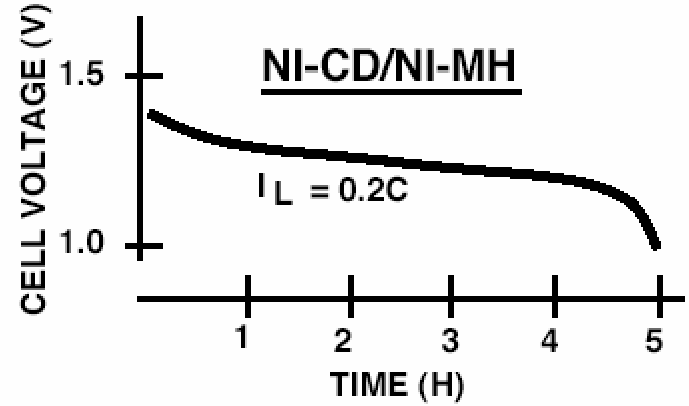




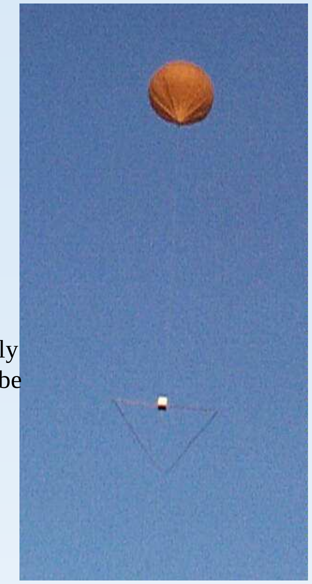
Discharge Curves

This important difference between the battery types means that Ni-Cd and Ni-MH cells are well suited for use with linear regulators, but Li-Ion batteries require switching converters to obtain good energy conversion efficiency in the power supply.





Batteries



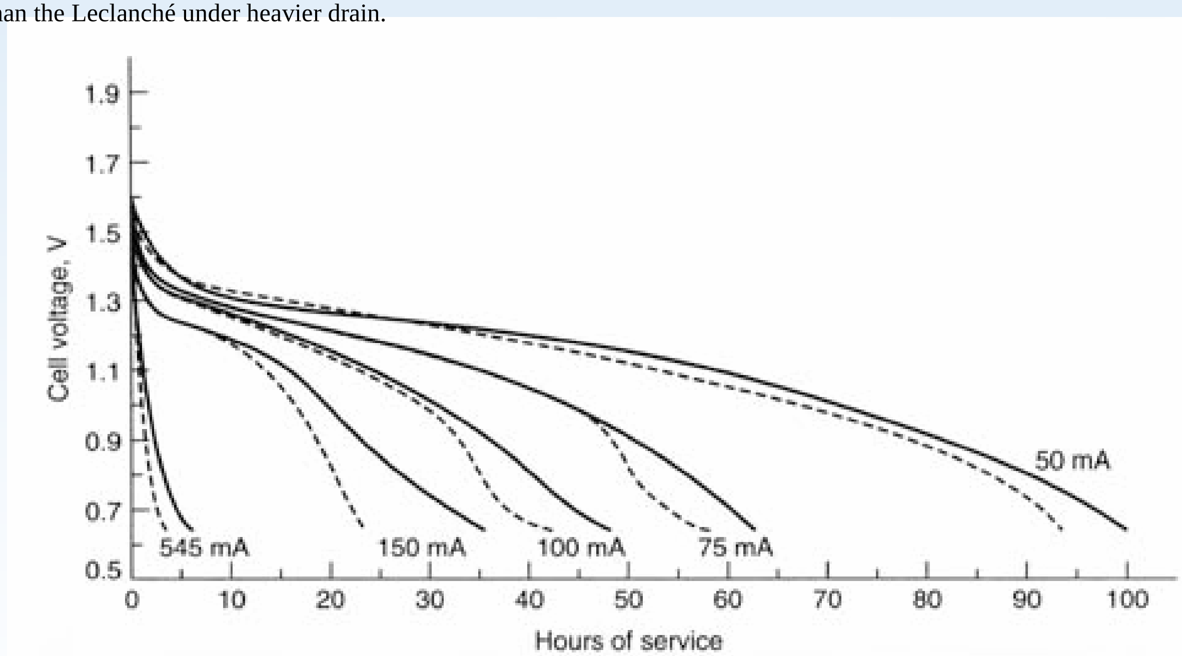
Anode: Zinc

Cathode: Manganese Dioxide (MnO_2)

Electrolyte: Ammonium chloride or zinc chloride dissolved in water

Applications: Flashlights, toys, moderate drain use

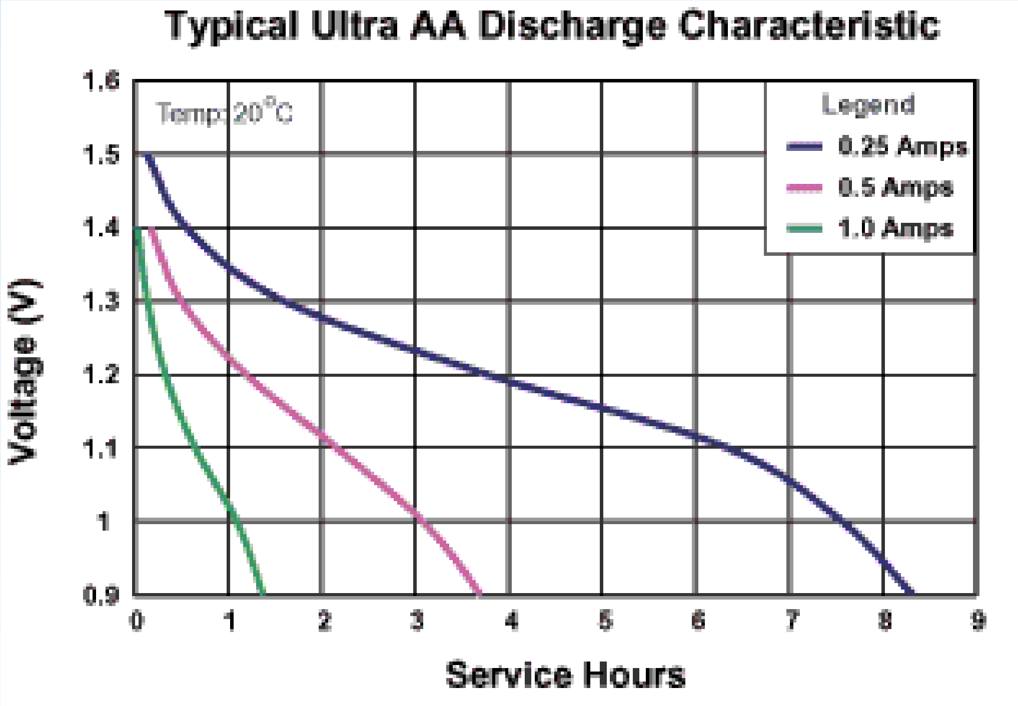
The basic design of the Leclanché cell has been around since the 1860s, and until World War II, was the only one in wide use. It is still the most commonly used of all primary battery designs because of its low cost, availability, and applicability in various situations. However, because the Leclanché cell must be discharged intermittently for best capacity, much of battery research in the last three decades has focused on zinc-chloride cell systems, which have been found to perform better than the Leclanché under heavier drain.

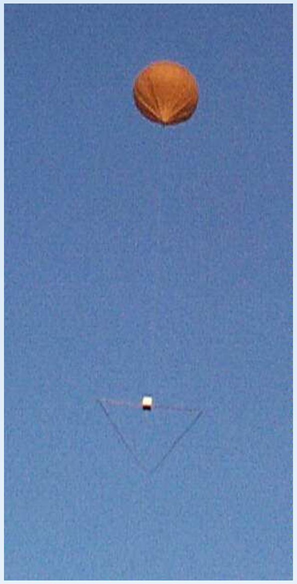


This figure shows typical discharge curves for general-purpose Leclanché zinc chloride D-size cells discharge 2 h/day at 20º C. Solid line—zinc chloride; broken line—Leclanché (Linden 8.18). *The zinc-chloride cell has a higher service life and voltage than the Leclanché (at both higher and lower discharge rates).*

In an ordinary Leclanché cell the electrolyte consists (in percent of atomic weight) of 26% NH_4Cl (ammonium chloride), 8.8% $ZnCl_2$ (zinc chloride), and 65.2% water. The overall cell reaction can be expressed: $Zn + 2MnO_2 + 2NH_4Cl \longrightarrow 2MnOOH + Zn(NH_3)_2Cl_2$ E=1.26

Alkaline Battery Discharge

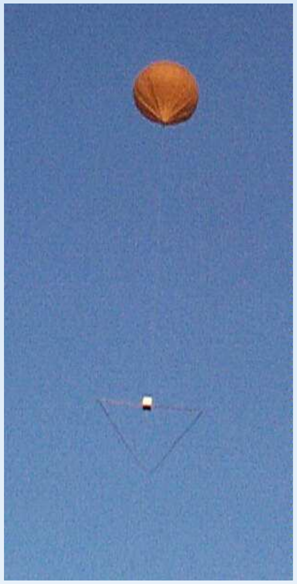


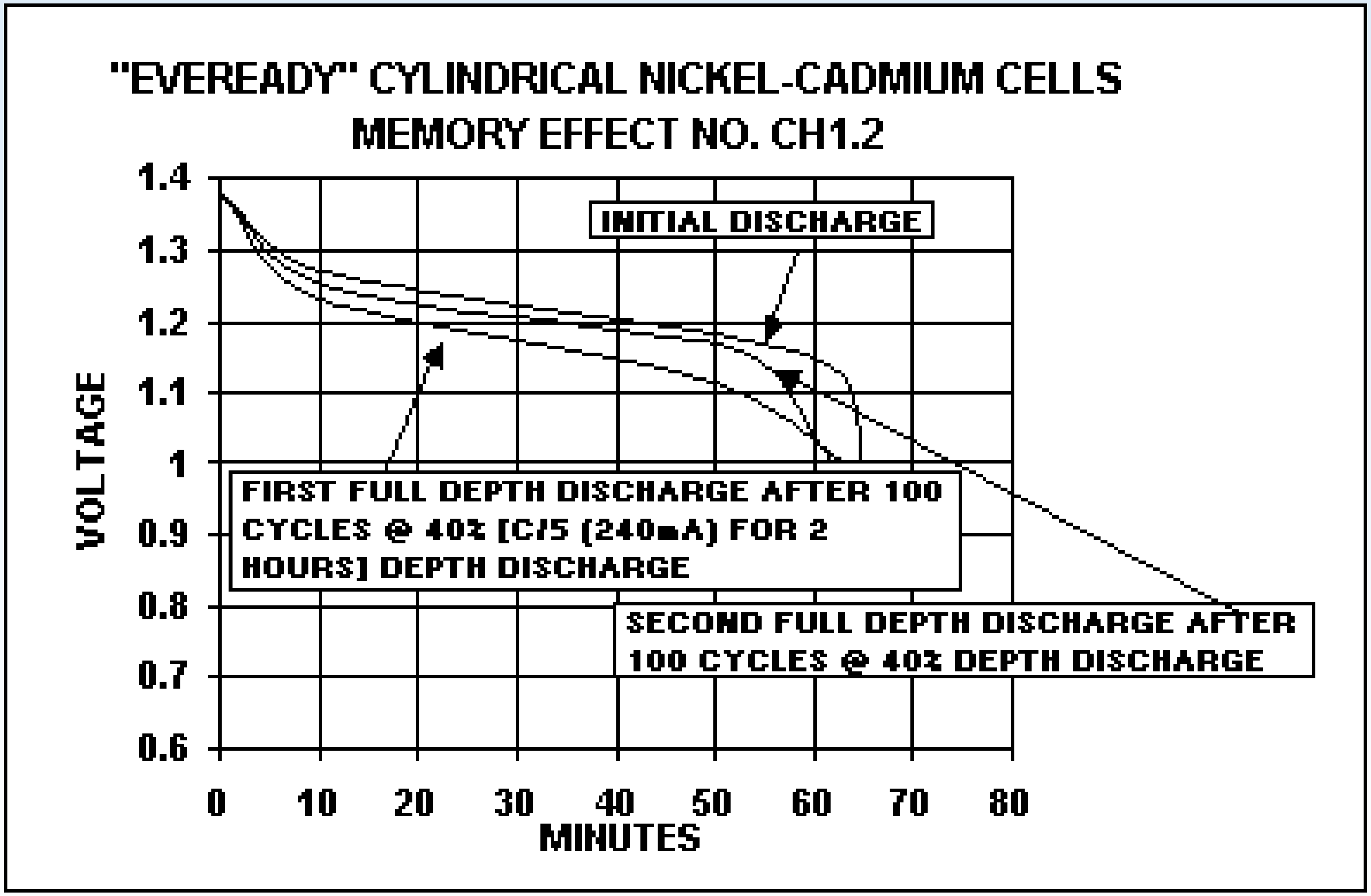


Notice how capacity drops off as Current increases

Batteries

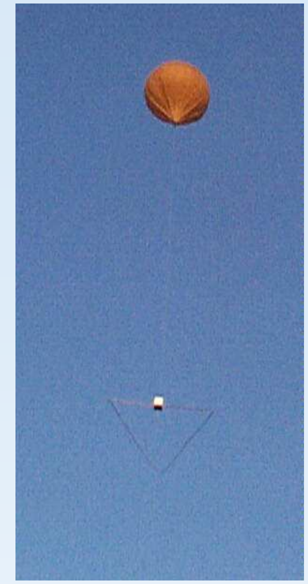
Memory Effect in NiCads





Batteries

Peak Current



The maximum current that a battery can deliver is directly dependent on the internal *equivalent series resistance* (ESR) of the battery.

The current flowing out of the battery must pass through the ESR, which will reduce the battery terminal voltage by an amount equal to the ESR multiplied times the load current (V = I X R).

More important, the current flowing through the ESR will cause power dissipation within the battery that is equal to the ESR multiplied times the current squared (P = I^2 X R). This can result in significant heating within the battery at high rates of discharge.

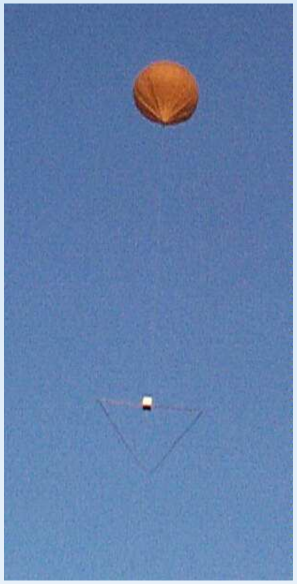
Both Ni-Cd and Ni-MH batteries have extremely low ESR values (well below 0.1Ω for a typical "AA" cell), which means that ESR is almost never a limitation for peak discharge current in these cell types.

The Li-Ion battery will typically have a higher ESR (compared to Ni-Cd or Ni-MH), but will probably not be a problem in most applications.

Li-Ion Batteries -- Maximum Current

About 2C for continuous discharge and 3C for instantaneous discharge. But these numbers can be changed by re-designing the battery. For example, by sacrificing about 25% capacity we can increase the maximum discharge rate to 6C.

Batteries



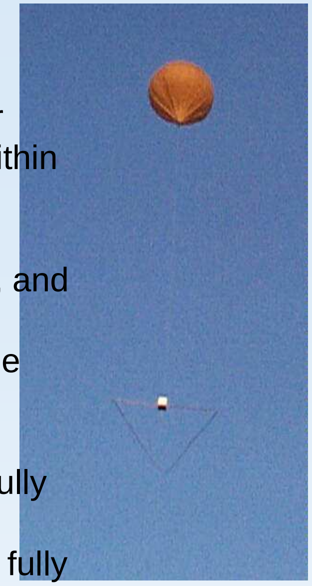
Self Discharge

Self-discharge (which occurs in all batteries) determines the "shelf life" of a battery.
In general, Li-Ion is the best of the lot, while Ni-Cd and Ni-MH are fairly comparable to each other. Ni-Cd is typically a little better than Ni-MH, but this may even out as Ni-MH manufacturing technology matures.
It is important to note that self-discharge is highly dependent on temperature, increasing as the battery temperature is increased.
Another unpleasant characteristic is that the discharge rate is extremely non-linear. A battery which loses 30% in a month may lose 15 to 20% in the first few days.

CELL TYPE	NI-MH	NI-CD	LI-ION
SELF-DISCHARGE @ 20°C (%/MONTH)	20-30	15-20	5-10

Batteries

Operating Temperature



Batteries are acutely sensitive to operating temperature with respect to their charging characteristics and A-hr capacity. Most well-designed chargers have temperature sensors to assure that the battery temperature is within the allowable "window" for charging (if not, the charger will not turn on the current source).

NI-CD/NI-MH

Battery makers generally recommend 0-50°C as the maximum operating limits for Ni-Cd and Ni-MH batteries, and typically restrict the allowable range to about 10-40°C for fast charging of the batteries.

These batteries work best at temperatures close to 25°C, as their characteristics change very quickly when the temperature deviates from this "ideal" point. At *elevated temperatures*, the cell experiences two undesirable effects:

a) The A-hr capacity of the cell reduces, meaning the cell will simply not deliver as much energy after being fully charged.

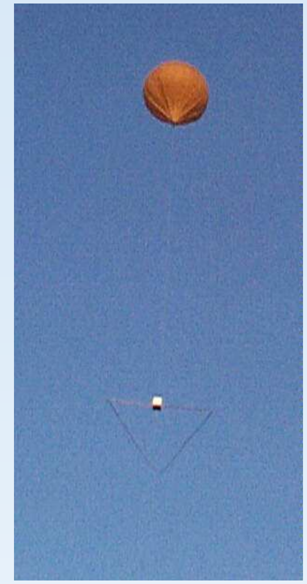
b) The cell gets "reluctant" to accept charge (the charging efficiency gets very bad) which makes it harder to fully charge the cell. This means that at high (>40°C) temperature, the charging efficiency can be so poor that 200 to 300% of the battery's total energy may have to be pumped in to it before it gets fully charged. At *low temperatures*, the maximum safe charging current that the cell can tolerate is lower because the gas does not recombine as readily within the cell. For optimum battery life, a charger should sense the temperature and reduce to maximum charge current at low temperatures. There is also a loss of cell capacity at low temperatures, although the effect is not nearly as pronounced as the reduction seen at high temperature.

LI-ION

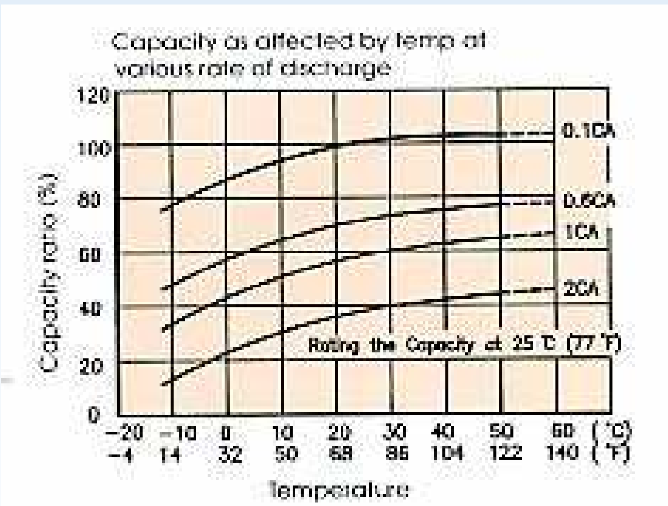
The Li-Ion cell can be safely charged at temperatures between 0-45°C. The operating temperature range during discharge is specified as -20 to 60°C. The small amount of information in published curves on the Li-Ion cell indicate that it is superior to Ni-Cd/Ni-MH in its performance over temperature. The Li-Ion cell does not suffer a significant capacity loss at high temperatures, as the discharge curves at 20°C and 60°C are virtually identical. There is a progressive loss of capacity at low temperatures, with the

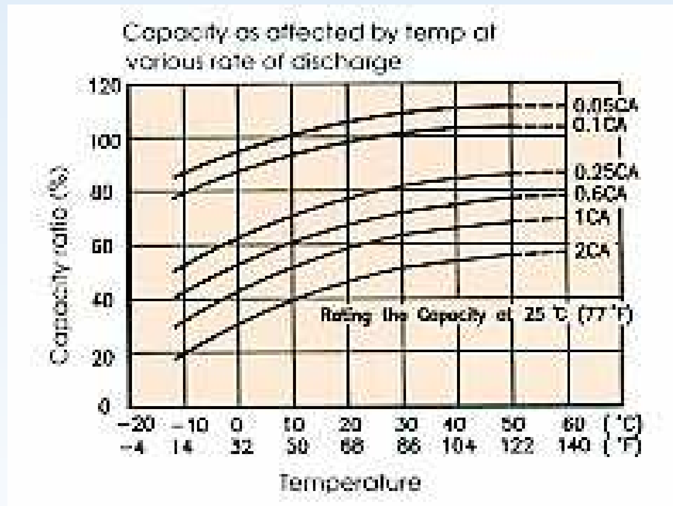
0°C delivered energy being about 90% of the 20°C amount, and at -20°C the cell delivers about 70% of the capacity that is delivered at 20°C.

Batteries



Chemistry	Volts per cell (V)	Temperature range (ºC)
NiCd	1.2	-35 to +70
NiMH	1.2	-5 to +70
Lead-acid	2	-65 to +65

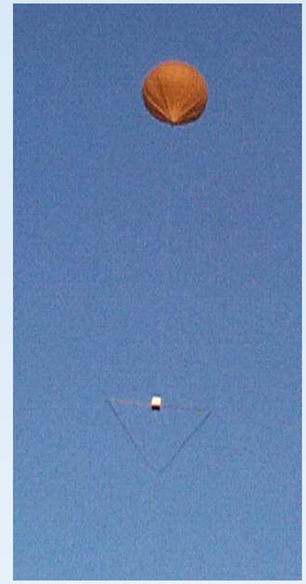




A battery life will be less at lower temperatures. As the temperature is lowered the electro-chemical activity lessens and the internal resistance increases. This does not mean that the higher the temperature, the longer life is achieved. Depending upon the type of battery, too high a temperature will cause chemical deterioration and loss of capacity. The main thing to remember is to keep batteries cool during storage and warm “never hot” during operation.

Batteries

Secondary Battery Info

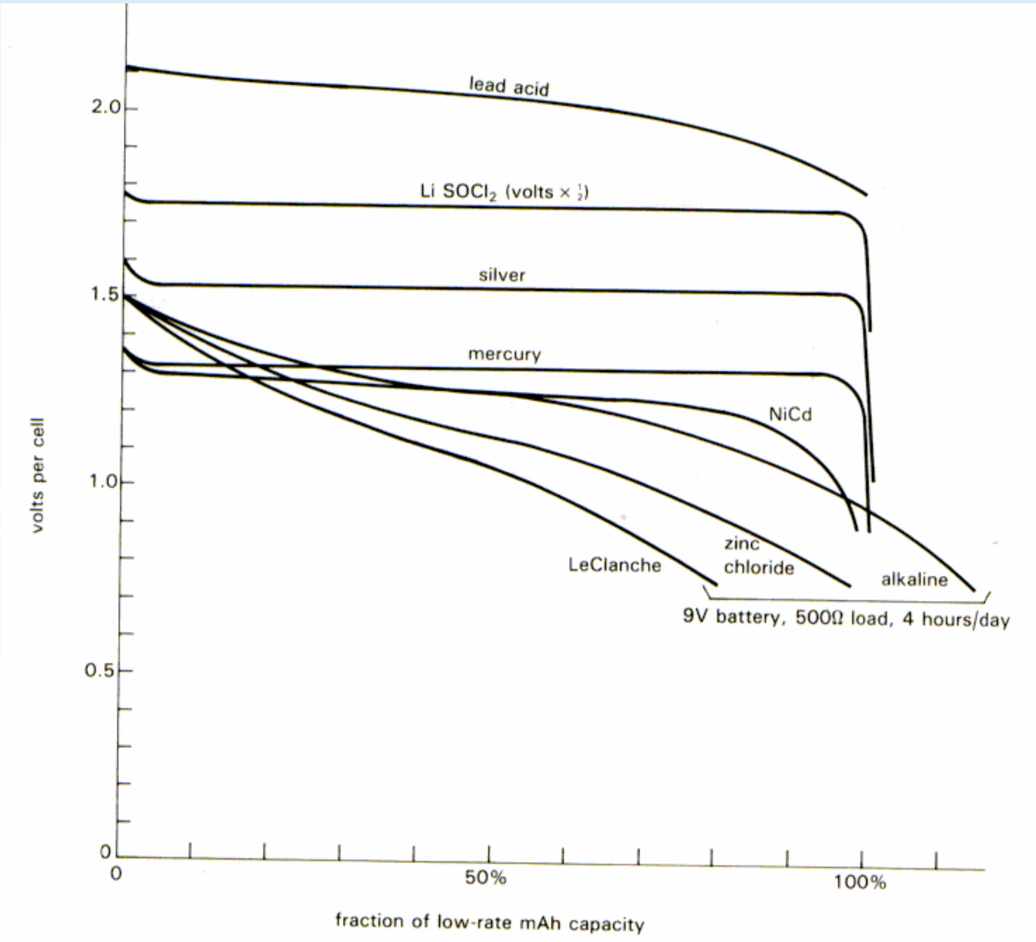


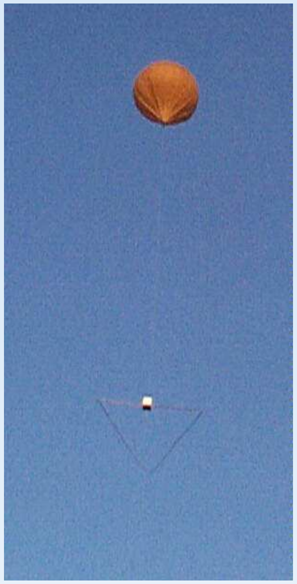
	Nickel-cadmium	Nickel-metal-hydride	Lead-acid	Lithium-ion	Lithium-ion-polymer	Reusable alkaline
Gravimetric Energy Density (Wh/kg)	45-80	60-120	30-50	110-160	100-130	80 (initial)
Internal Resistance (includes peripheral circuits) in mΩ	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 to 250[1] 7.2V pack	200 to 300[1] 7.2V pack	200 to 2000[1] 6V pack
Cycle Life (to 80% of initial capacity)	1500[2]	300 to 500[2,3]	200 to 300[2]	300 to 500[3]	300 to 500	50[3] (to 50% capacity)
Fast Charge Time	1h typical	2 to 4h	8 to 16h	2 to 4h	2 to 4h	2 to 3h
Overcharge Tolerance	moderate	low	high	very low	low	moderate
Self-discharge / Month (room temperature)	20%[4]	30%[4]	5%	10%[5]	~10%[5]	0.3%
Cell Voltage (nominal)	1.25V[6]	1.25V[6]	2V	3.6V	3.6V	1.5V
Load Current peak best result	20C 1C	5C 0.5C or lower	5C[7] 0.2C	>2C 1C or lower	>2C 1C or lower	0.5C 0.2C or lower
Operating Temperature[8] (discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C	0 to 65°C
Maintenance Requirement	30 to 60 days	60 to 90 days	3 to 6 months[9]	not required	not required.	not required
Typical Battery Cost[10] (US$, reference only)	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)	$5 (9V)
Cost per Cycle (US$)[11]	$0.04	$0.12	$0.10	$0.14	$0.29	$0.10-0.50
Commercial use since	1950	1990	1970	1991	1999	1992
Toxicity	Highly toxic, harmful to environment	Relatively low toxicity, should be recycled	Toxic lead and acids, harmful to environment	Low toxicity, can be disposed in small quantities	Low toxicity can be disposed in small quantities	Low toxicity, may contain mercury

1) Internal resistance of a battery pack varies with cell rating, type of protection circuit and number of cells. Protection circuit of lithium?ion and lithium-ion-polymer adds about 100mW.
2) Cycle life is based on battery receiving regular maintenance. Failing to apply periodic full discharge cycles may reduce the cycle life by a factor of three.
3) Cycle life is based on the depth of discharge. Shallow discharges provide more cycles than deep discharges.
4) The discharge is highest immediately after charge, and then tapers off. The capacity of nickel-cadmium decreases 10% in the first 24h, then declines to about 10% every 30 days thereafter. Self-discharge increases with higher temperature.
5) Internal protection circuits typically consume 3% of the stored energy per month.
6) 1.25V is the open cell voltage. 1.2V is the commonly used as a method of rating.
7) Capable of high current pulses.
8) Applies to discharge only; charge temperature range is more confined.
9) Maintenance may be in the form of 'equalizing' or 'topping' charge.
10) Cost of battery for commercially available portable devices.
11) Derived from the battery price divided by cycle life. Does not include the cost of electricity and chargers.

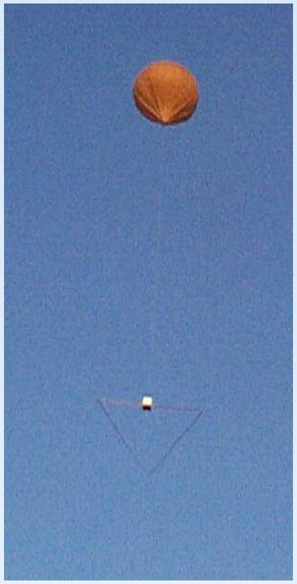
Batteries

Discharge Curves (low current)

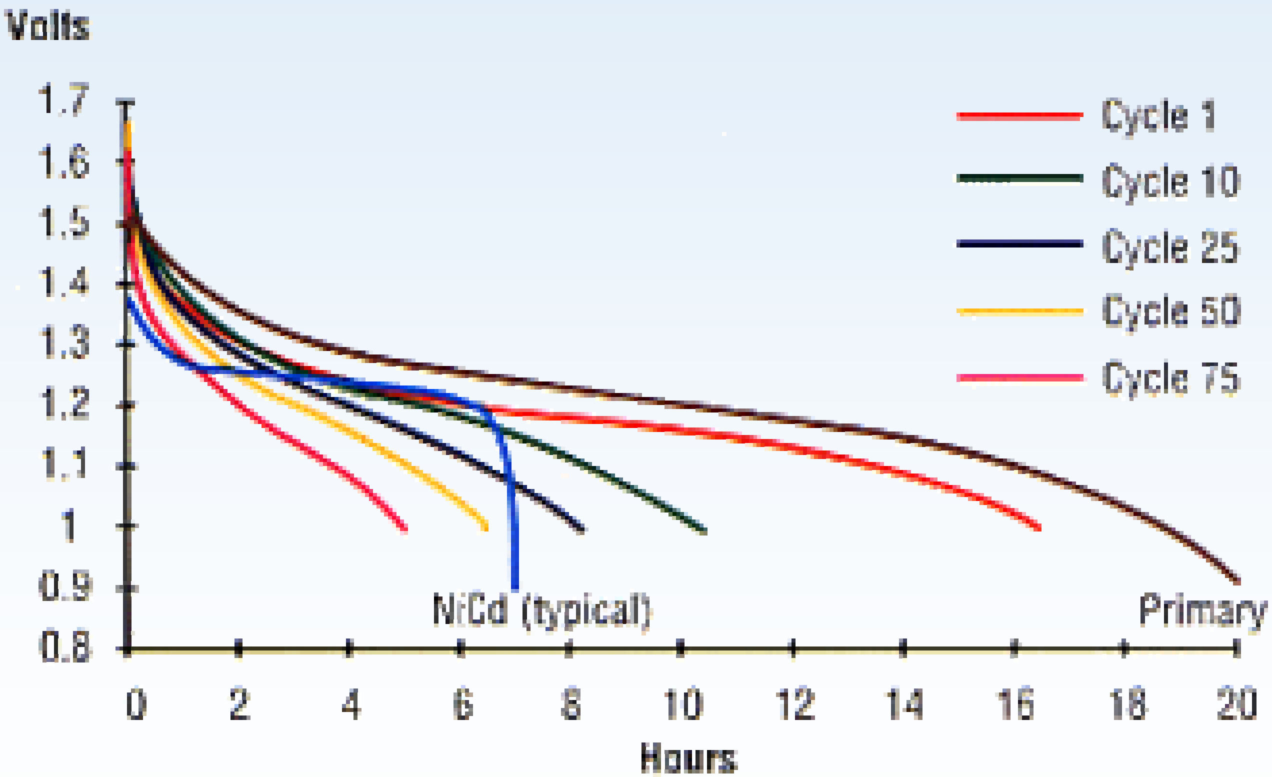




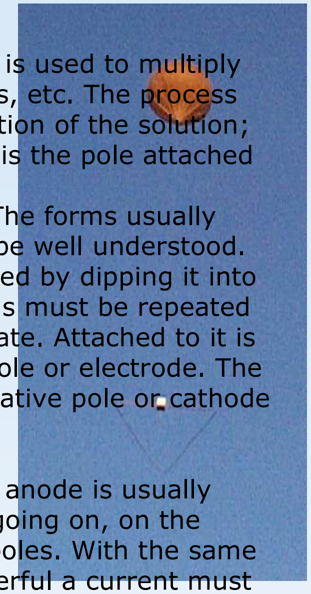
Batteries



NiCd v Alkaline Discharge



Batteries



Galvanoplasty or Electrotype, is the art of cold casting of metals by the agency of electricity. Its applications are extensive. It is used to multiply engravings and photographs; to cover the faces of types with harder metal; to deposit grad, silver, and alloys on other metals, etc. The process depends upon the fact that an electrical current passed through a metallic solution properly prepared, will cause a decomposition of the solution; the metal being deposited upon any conducting body attached to the negative pole (cathode) of a voltaic cell or battery. This is the pole attached to the zinc plate in all cases.

The term battery is properly applied to several voltaic cells united. Frequently, however, it is used to designate a single cell. The forms usually employed in practice are Smee's, Daniell's, and the nitric acid battery. In order to avoid confusion, the following points must be well understood. In all the batteries named, there are two plates and at exciting fluid. One of these plates is of zinc, which must be amalgamated by dipping it into weak sulphuric acid and rubbing the surface with mercury; or better still, immersing the whole plate in a bath of mercury. This must be repeated from time to time, when the battery is in use. This zinc plate is alone acted on by the exciting fluid. It is galled the positive plate. Attached to it is a binding screw, by which a wire may be connected with the plate. This screw, or the end of the attached wire, is called the pole or electrode. The name of the pole is opposite to that of the plate. The positive pole or anode being attached to the negative plate, and the negative pole or cathode to the positive (zinc) plate.

The Decomposing Cell

Usually the liquid to be decomposed (electrolyte) is kept in a separate vessel, and the current conveyed to it by wires. To the anode is usually attached a piece of metal of the same character as that to be deposited. This is gradually eaten away while the deposition is going on, on the cathode, and the solution thus kept of uniform strength. The current may be regulated by altering the distance between the poles. With the same battery power, the amount of electricity passing will be less as the distance of the poles in the electrolyte is greater. Too powerful a current must be avoided, as it renders the coating brittle and non-adherrent. It should not be strong enough to cause bubbles of gas to arise from the object. A large number of objects can be plated by one battery if they are suspended on copper rods, the ends of which are connected with the pole.

Smee's Cell

Consists of two plates of amalgamated zinc, separated by a piece of baked and varnished wood and between them a plate of silver having deposited on it by the electric current finely divided platinum; so as to roughen it and prevent the adhesion of hydrogen. The silver plate is fixed in the wood separating the zinc plates, to the zinc and to the silver plates are attached binding screws for the wires. The exciting fluid is dilute sulphuric acid; 1 part of acid to 20 of water, is strong enough. When more intensity is required several cells are joined by passing wires from the anode of one cell to the cathode of the next. This form of battery is generally preferred on account of its simplicity, constancy, and ease of management.

Daniell's Cell

In delicate operations, as in copying engraved plates, where great constancy is required, this form of cell is employed. It consists of a plate of amalgamated zinc, one of copper, generally of cylindrical form separated by a cell of porous earthenware (a flower-pot with the hole closed by a cork, makes a very good porous cell). The plates and cell are enclosed in a glass or earthenware vessel; the zinc is excited by dilute sulphuric acid; the copper is kept immersed in saturated solution of sulphate of copper (blue-stone). The solution of copper is gradually decomposed; the copper being deposited in the copper plate. Hence there should always be a quantity of crystals of the sulphate at the bottom of the cell, and the solution should be stirred from time to time; or the crystals may be suspended in a basket near the top of the solution

Nitric Acid Batteries

When great intensity is required as in the deposition of copper on iron, and of certain alloys the decomposition of fused chlorides for the purpose of obtaining certain metals, these batteries are used. In all cases the positive plate is of amalgamated zinc excited by dilute sulphyric acid, which may be as strong as 1 in 10 with 1-10th of nitric acid. This is separated by a porous cell from the negative plate, which may be of platinum (Grove), carbon (Bunsen), or passive iron (Callan). The negative plate is immersed in strong nitric acid. Iron may be rendered passive by dipping it once or twice into strong nitric acid, and then washing with water and carefully drying.